Gravitational heating, clumps, overheating

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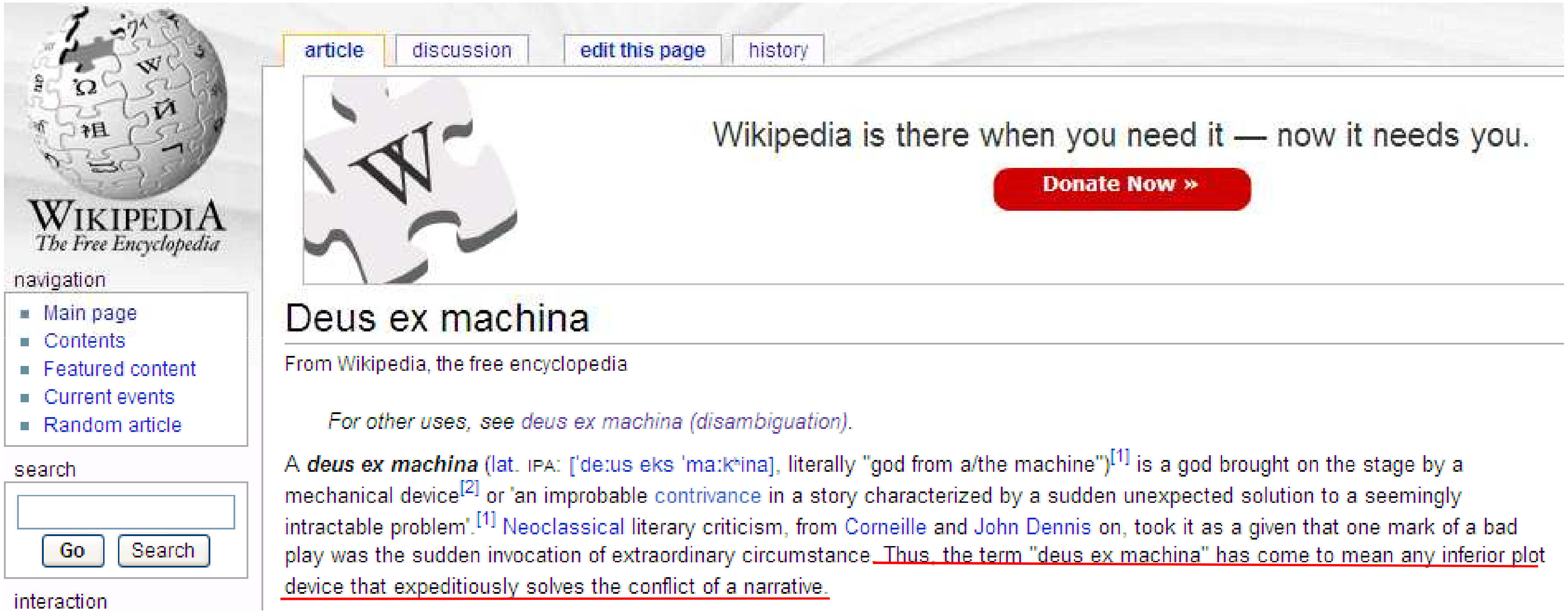
Basic idea:

- Cooling flow Clusters need additional energy to reduce cooling rate and SFR of CD galaxy
- Possible mechanisms:
  - AGN feedback (Deus ex Machina)
  - Transferring energy from outer halo to the center
    - Conduction (probably ruled out)
    - Heating by mass & energy injection from the outer-halo.

Accreted cold clumps can pump energy to the center

Feasibility test



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Deus ex machina

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For other uses, see deus ex machina (disambiguation).

A ***deus ex machina*** (lat. IPA: ['de:us eks 'ma:kʰina], literally "god from a/the machine")[1] is a god brought on the stage by a mechanical device[2] or 'an improbable contrivance in a story characterized by a sudden unexpected solution to a seemingly intractable problem'.[1] Neoclassical literary criticism, from Corneille and John Dennis on, took it as a given that one mark of a bad play was the sudden invocation of extraordinary circumstance. Thus, the term "deus ex machina" has come to mean any inferior plot device that expeditiously solves the conflict of a narrative.

See also: magnetic fields

Outline

1. Tapping into the gravitational energy reservoir
2. Coupling the inner halo to the outer world
3. Global and local stability of heating mechanisms
4. 1D Hydro-simulation results

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1. Tapping into the gravitational energy reservoir

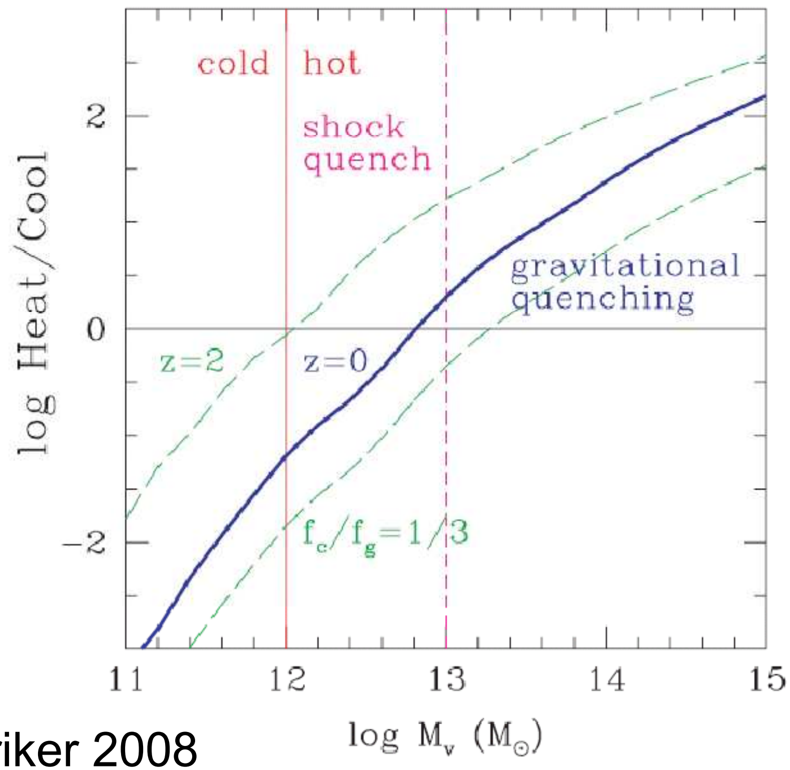
- Halos of $M_{vir} \geq 10^{13} M_\odot$ have enough E_{grav} to compensate for cooling

- Calculation parameters:
  profile: NFW total w isothermal gas
  Accretion rate: Wechsler et al. 2002

$$f_{gas} = 0.05 \qquad Z = 0.3 Z_\odot$$

$$f_{clump} = 0.05 \qquad z = 0$$

$$f_{bar} = f_{gas} + f_{clump} \qquad R_{penetration} = 0.1 R_{vir}$$



Dekel & Birnboim 2008, see also Khochfar & Ostriker 2008

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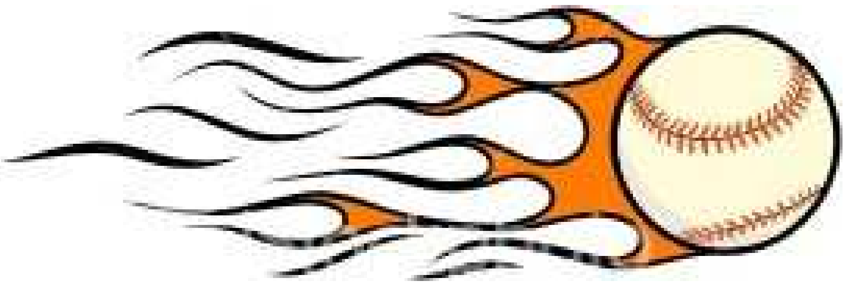
2. Coupling the inner halo to the outer world

Heating by baryonic cold clumps

Physical processes of clump:

1. Hydrodynamic drag
2. Jeans mass (Bonnor-Ebert)
3. K-H/R-T instabilities and clump fragmentation
4. DF (marginally works)
5. Conduction/evaporation

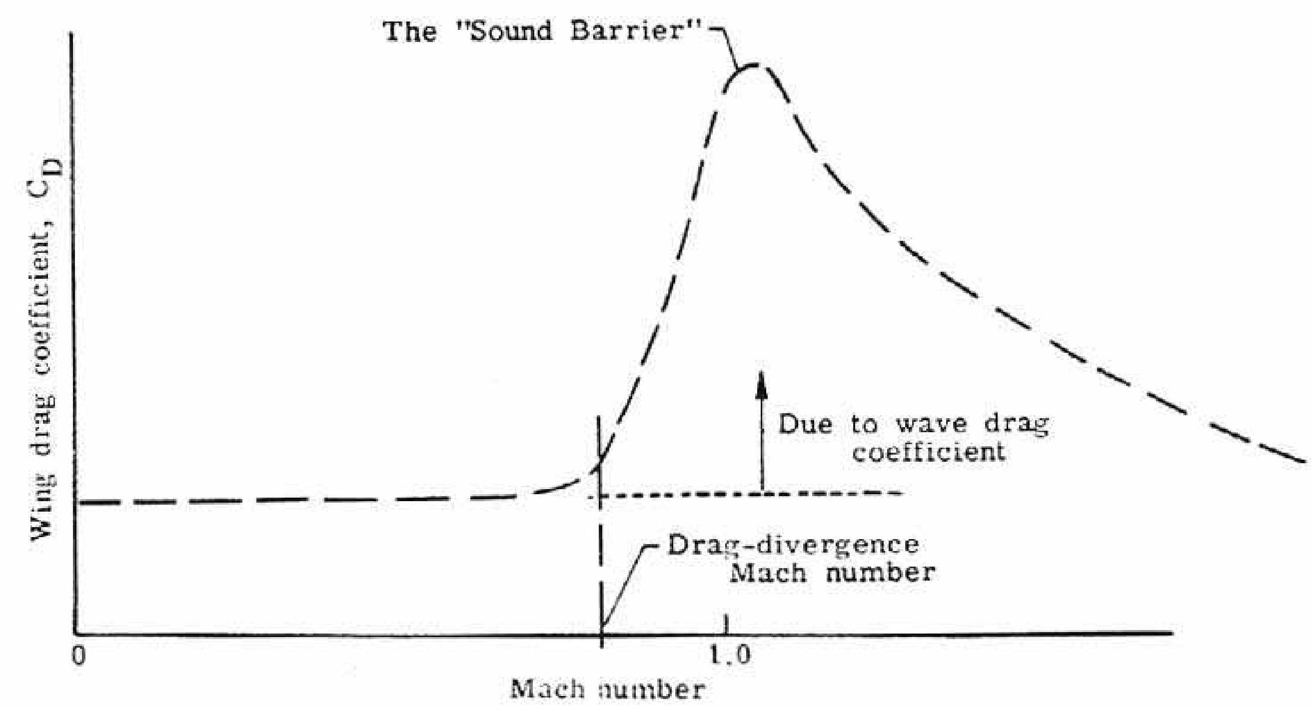


Requirements for effective heating:

1. Enough energy
2. Qusai-Hydrostatic halo
3. Enough clumps
4. Correct mass range of clumps

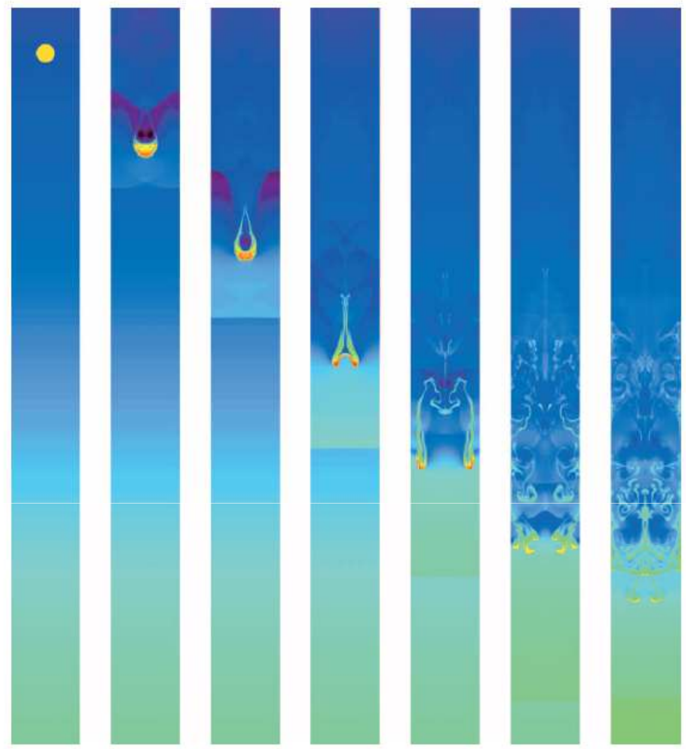
Hydrodynamic drag

$$F_{drag} = -\frac{1}{2} C_d \rho_{halo} \pi r_{clump}{}^2 v_{shear}$$



Clump Survivability

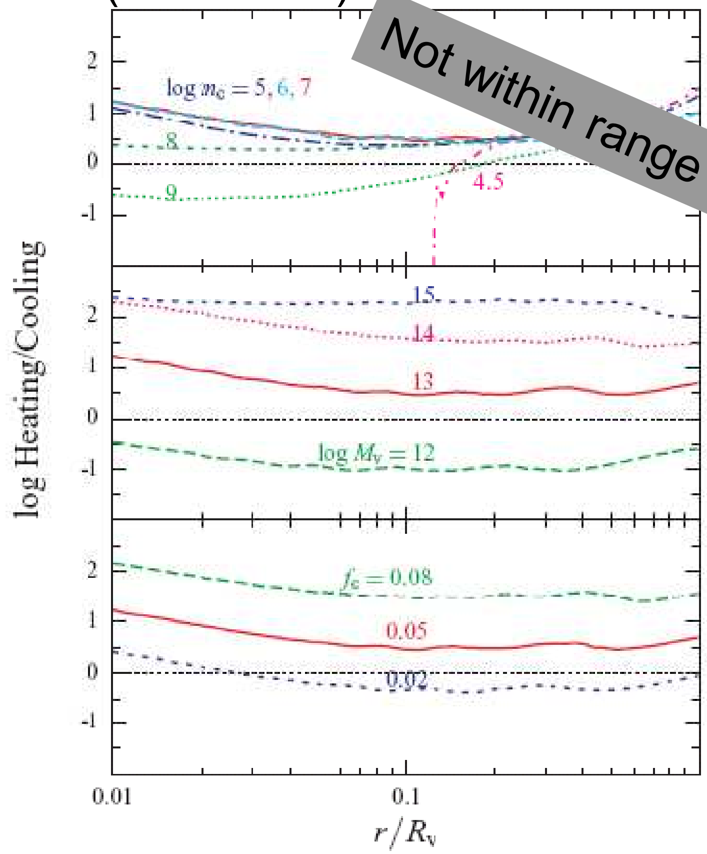
1) Energy goes to the hot diffuse component
2) Clump fragments after repelling ones weight in diffuse gas

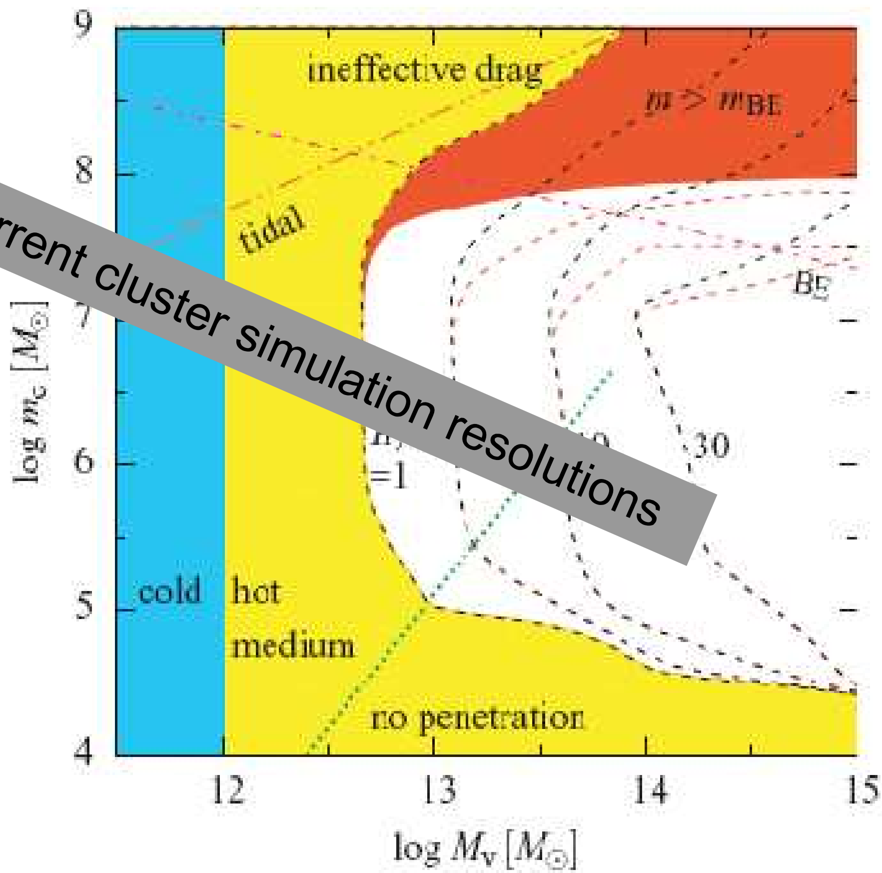


Murray & Lin 2004

2. Coupling of the inner halo to the outer world (cntd.)

Monte-Carlo of many clumps (static halo)





Not within range of current cluster simulation resolutions

The fiducial case:
$M_v = 10^{13} M_\odot$, $m_c = 10^7 M_\odot$, $f_b = 0.1$, $f_c = 0.05$

2. Coupling of the inner halo to the outer world (cntd.)

- Open questions:
  - How to produce these clumps
  - Mass deposition is near center (can we have our cake and eat it?)
  - Need to start the process with realistic I.C.
  - Can the halo remain dynamically stable when H/C≠0.

YES!

- Clumps alternatives:
  - cold flows splashing at the inner halo
  - large scale turbulence
  - conduction

Origin of clumps

- DM subhalos will loose gas
- Cooling fragmentation in filaments, outskirts of cluster can be birthplace of clumps

Note: missing baryon problem in clusters!

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3. Global and local stability of heating mechanisms

- Clump Heating, Radiation heating by AGN etc. are proportional to density
- Fields (65), Conroy & Ostriker (07) note that such gas is cooling unstable:

$$\text{hydrostatic equilibrium}: \ \rho \mathrm{T} = const$$

$$\begin{aligned} &\text{cooling}: && \propto \Lambda(T)\rho^2 \propto \rho^{1.5} \\ &\text{heating}: && \propto \rho \end{aligned} \quad \Rightarrow \quad \frac{H}{C} \propto \rho^{-0.5}$$

- Cooling instability is always a heating instability!

  → unstable heating → entropy inversion → convection

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"Hydra" 1D spherical Lagrangian code

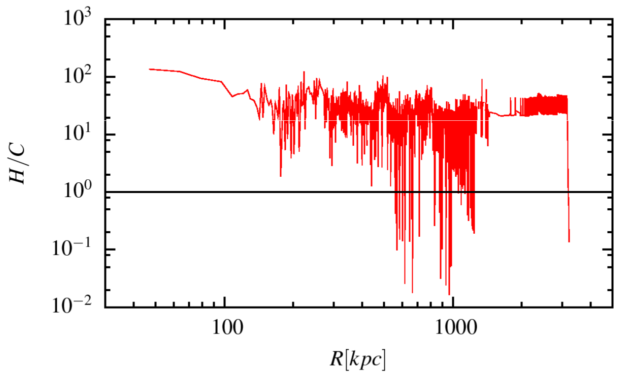
New components:

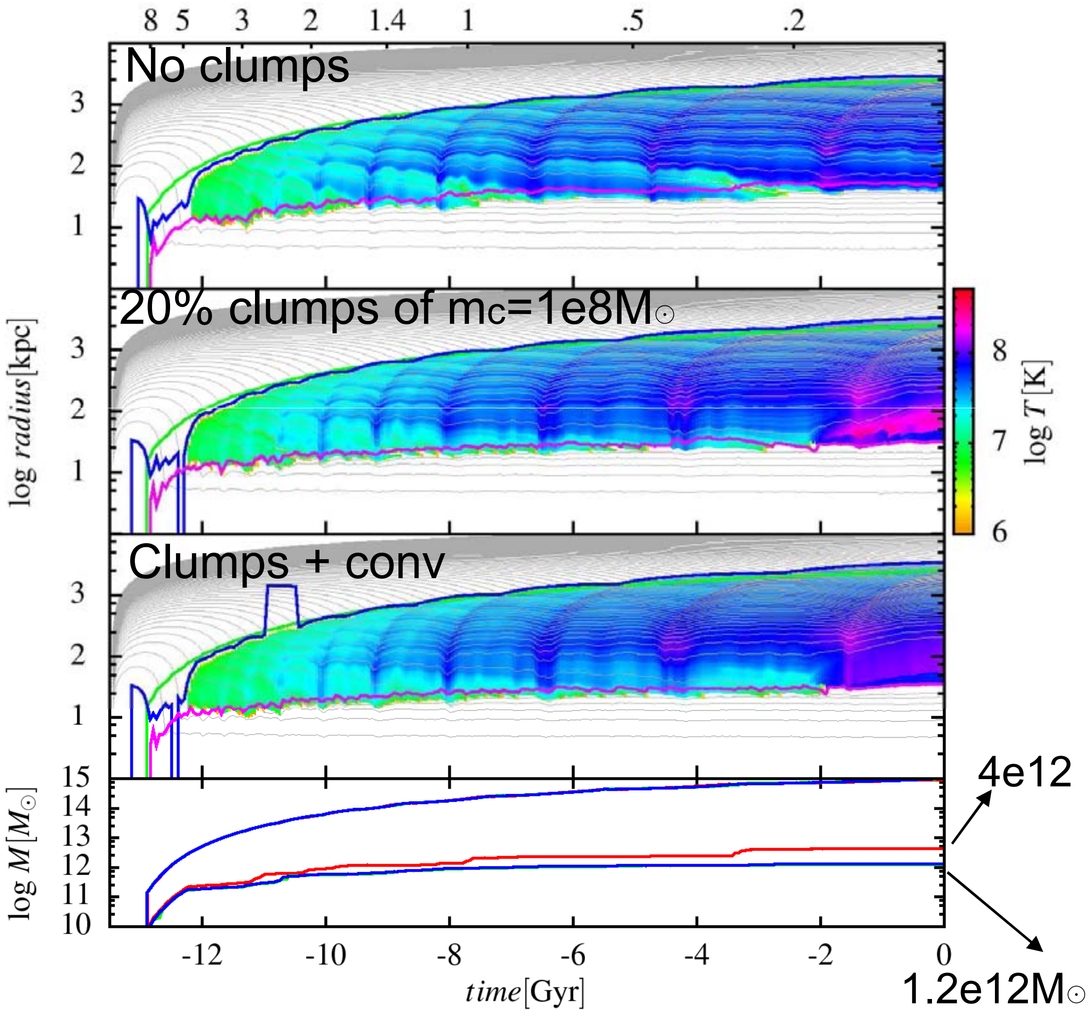
- Sub-grid model for clumps
  - clump shells are DM shells with extra forces
  - heating, momentum transfer
  - mass injection when clumps disintegrate
- Lagrangian AMR (shell splitting)
- Convection (1D Mixing length theory)

4. 1D Hydro-simulation results

M_{vir}=1e15M⊙

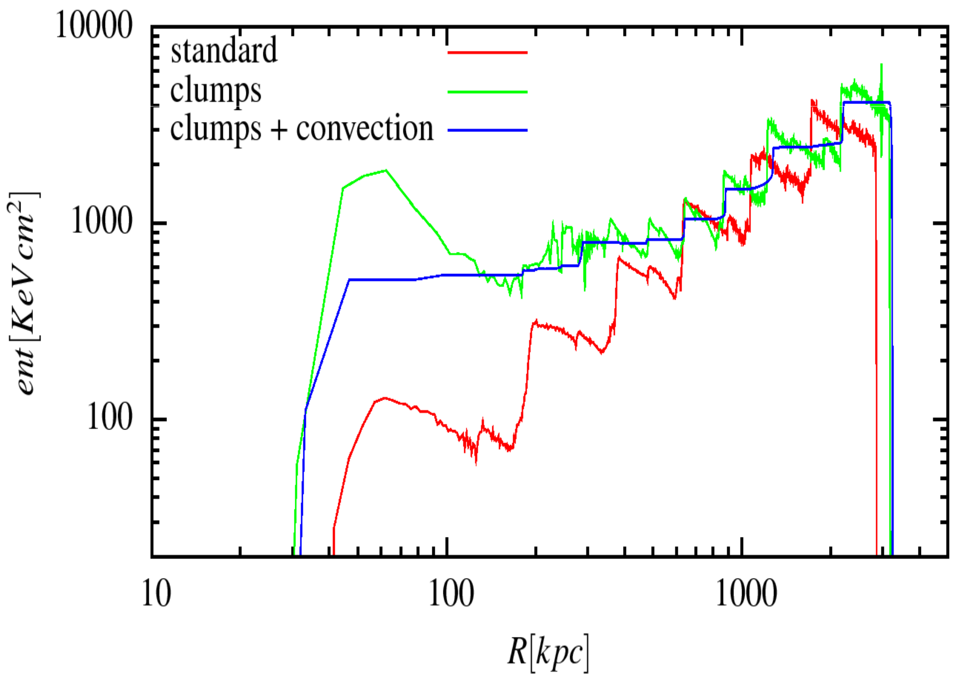
very efficient heating!
(>1e45 erg/sec since z=1)





4. 1D Hydro-simulation results

Effects of convection



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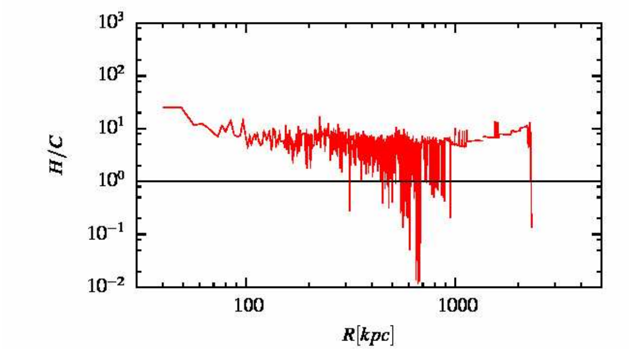

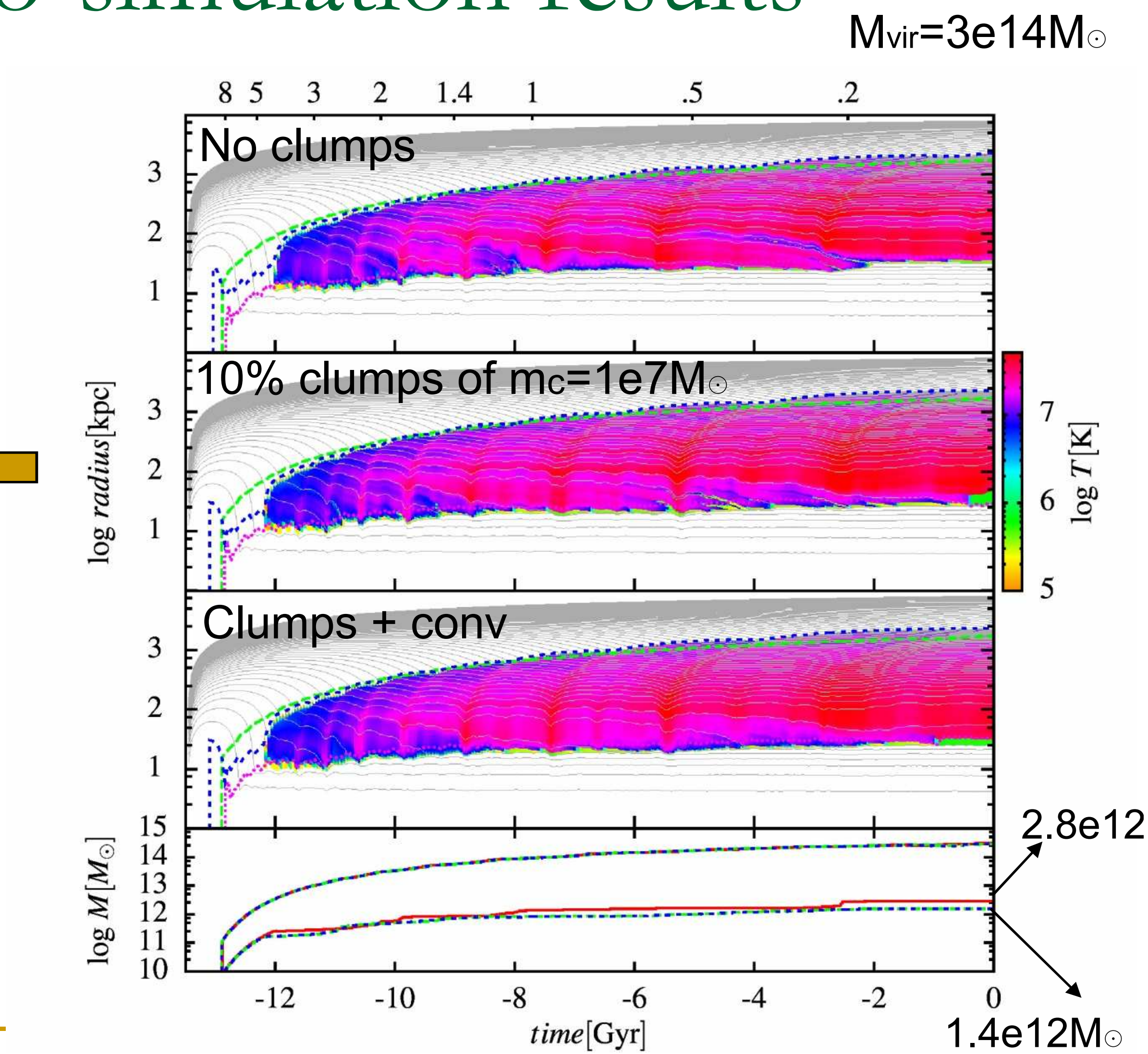

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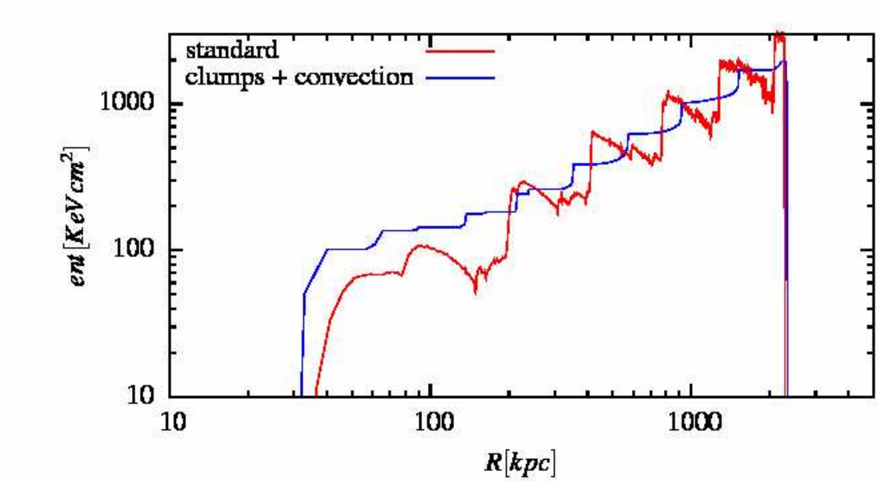

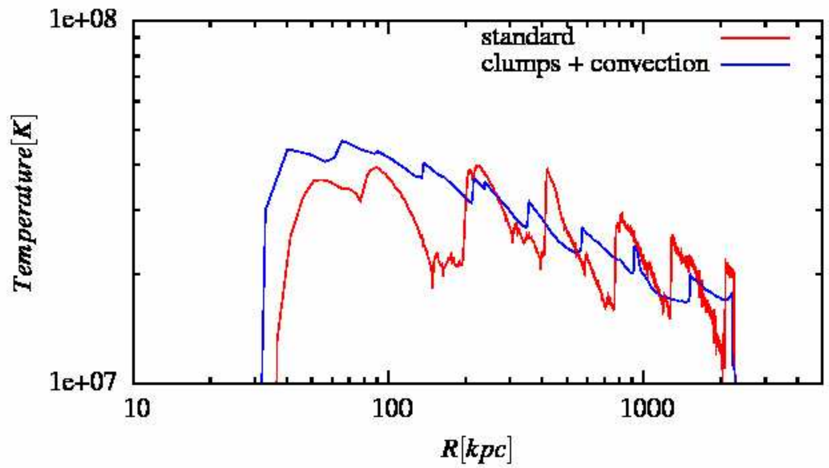

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Summary

- Gravitational energy can balance cooling
- Clumps couple naturally to the inner parts of clusters
- Cooling instability is local, heating invokes convection. But there is no global effect
- heating strangles central galaxy and shuts down star formation
- Fun, cool problem to work on

5. Cold Flows and the greater scheme

- No hot hydrostatic gas: Cold flows → rapid star formation
- hot gas halo: energy input wins over cold mass input → star formation shut-down